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Ultimate Graphics Performance for DirectX 10 Hardware

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V1.01

Generic API Usage

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DX10 designed for performance

- No legacy code
- No fixed function
- Validation at creation time
- Immutable state objects
- User mode driver
- Powerful API

Microsoft® DirectX® 10

State Management

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DX10 uses immutable “state objects”

DX10 state objects require a new way to manage states

- A naïve DX9 to DX10 port ***will*** cause problems here
- Always create state objects at load-time
- Avoid duplicating state objects
- Recommendation to sort by states still valid in DX10!

Constant Buffers Management

Major cause of slow performance in current DX10 apps!

Constants are declared in buffers in DX10

```
cbuffer PerFrameUpdateConstants
{
    float4x4 mView;
    float    fTime;
    float3   fWindForce;
    // etc.
};
```

```
cbuffer SkinningMatricesConstants
{
    float4x4 mSkin[64];
};
```

When a CB has been updated and bound to a shader stage its ***whole*** contents are uploaded to the GPU

Need to strike a good balance between:

- Amount of constant data to upload
- Number of calls required to do it

Constant Buffers Management (2)

Always use a pool of constant buffers ***sorted by frequency of updates***

- Don't go overboard with number of CBs!
- Less than 5 is a good target
- CB sharing between shader stages can be a good thing

Global constant buffer unlikely to yield good performance

- Especially with regard to CB contention

Group constants by access patterns in a given buffer

```
cbuffer PerFrameConstants
{
   float4   vLightVector;
   float4   vLightColor;
   float4   vOtherStuff[32];
};
```

GOOD

```
cbuffer PerFrameConstants
{
   float4   vLightVector;
   float4   vOtherStuff[32];
   float4   vLightColor;
};
```

BAD

Resource Updates

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In-game creation and destruction of resources is slow!

- Runtime validation, driver checks, memory allocation...

Take into account for resource management

- Especially with regard to texture management

Create all resources in non-performance situations

- Up-front, level load, cutscenes, etc.

At run-time *replace* contents of existing resources rather than destroying/creating new ones

Resource Updates: Textures

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Avoid **`UpdateSubresource()`** for texture updates

- Slow path in DX10 (think **`DrawPrimitiveUP()`** in DX9)
- Especially bad with larger textures!
- E.g. texture atlas, imposter pages, streaming data...

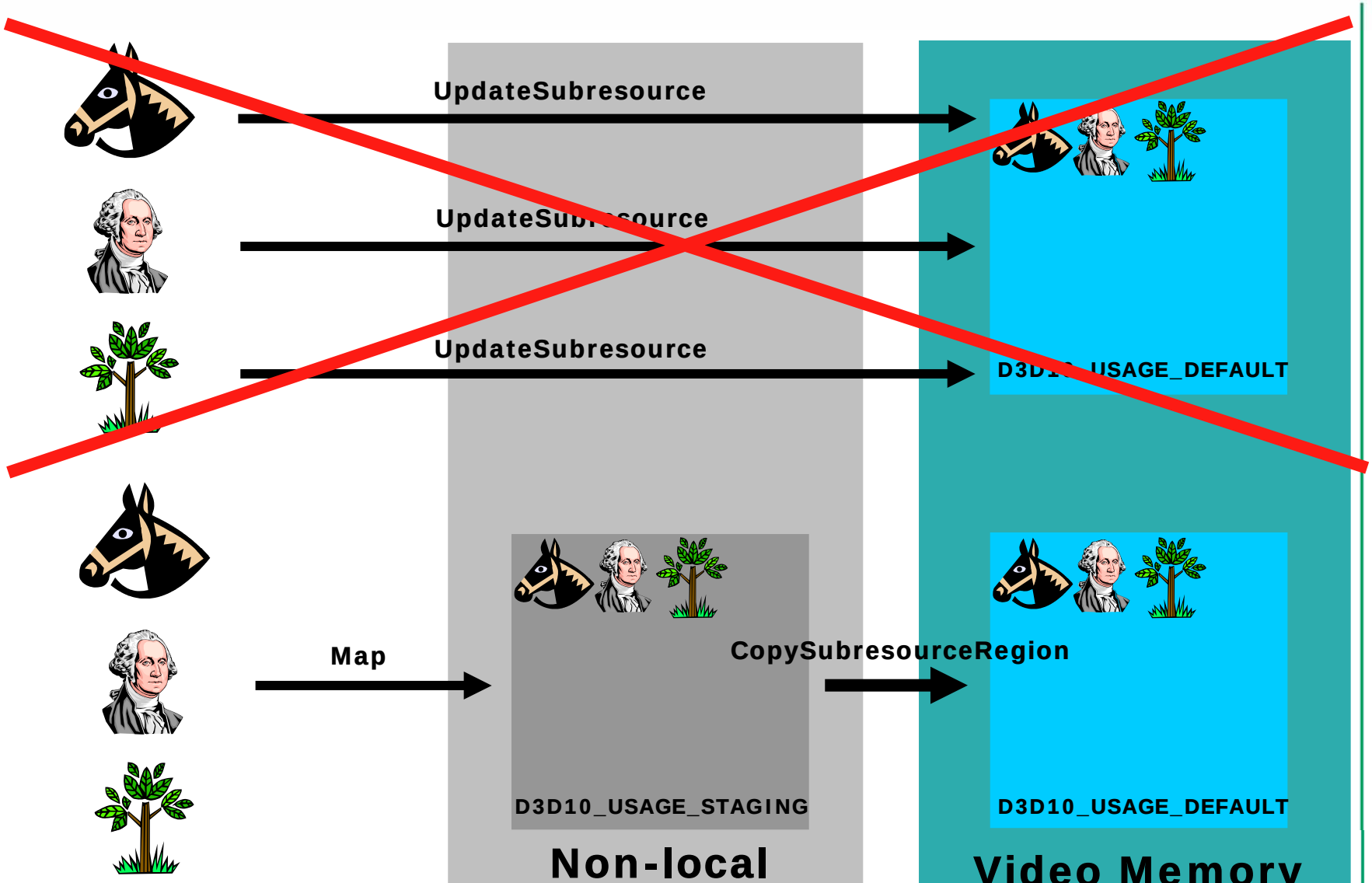
Perform all updates into pool of **`D3D10_USAGE_STAGING`** textures

- Use **`Map(D3D10_MAP_WRITE, ...)`** with **`D3D10_MAP_FLAG_DO_NOT_WAIT`** to avoid stalls

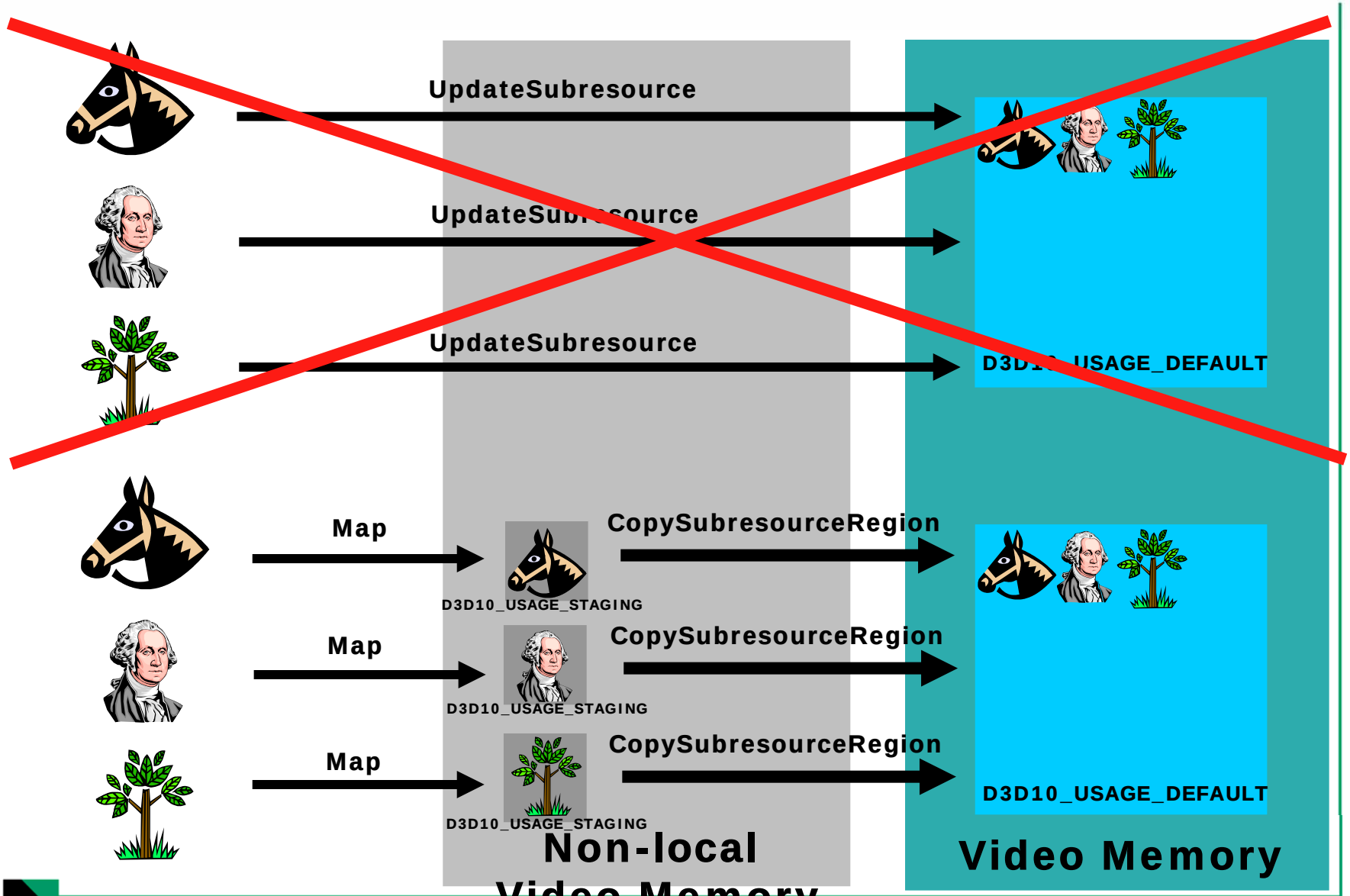
Then upload staging resources into video memory

- **`CopyResource()`**
- **`CopySubresourceRegion()`**

Resource Updates: Textures (2)



Resource Updates: Textures (3)



Resource Updates: Buffers

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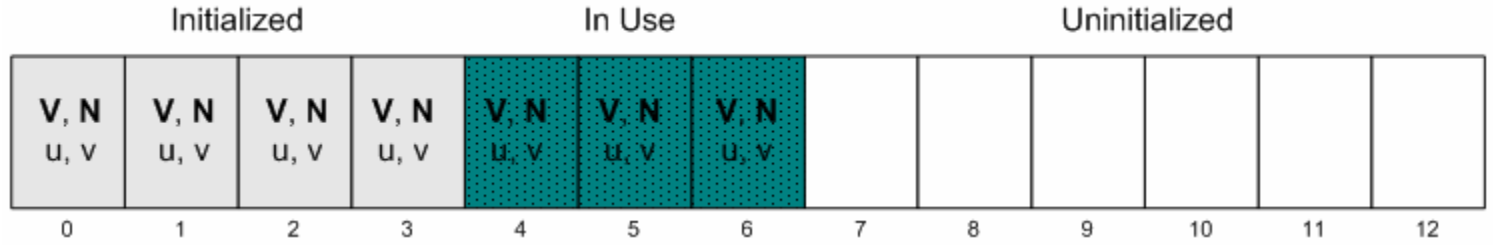
To update a Constant buffer

- Map(D3D10_MAP_WRITE_DISCARD, …);
- UpdateSubResource()

To update a dynamic Vertex/Index buffer

- **`Map(D3D10_MAP_WRITE_NO_OVERWRITE, …);`**
- Ring-buffer type; only write to empty portions of buffer
  - **`Map(D3D10_MAP_DISCARD)`** when buffer full
- UpdateSubresource() not as good as Map() in this case



DX10 Batch Performance

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The truth about DX10 batch performance

“Simple” porting job will not yield expected performance

Need to use DX10 features to yield gains:

- Geometry instancing
- Intelligent usage of state objects
- Intelligent usage of constant buffers
- Texture arrays

Geometry Shader Recommendations

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GS can write data out to memory

- This gives you “free” ALUs because of latency

Minimize the size of your output vertex structure

- Yields higher throughput
- Allows more output vertices (max output is 1024 floats)
- Consider adding pixel shader work to reduce output size

Geometry Shader Recommendations 2

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Cull triangles in Geometry Shader

- Backface culling
- Frustum culling

Minimize the size of your input vertex structure

- Combine inputs into single 4D iterator (e.g. 2 UV pairs)
- Pack data and use ALU instructions to unpack it
- Calculate values instead of storing them (e.g. binormal)

Color Clears

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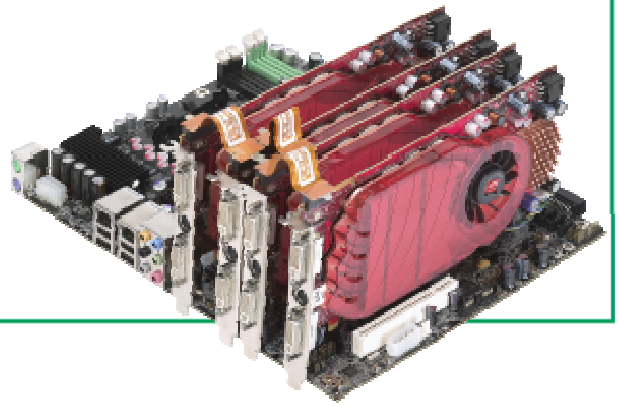
Clearing of color render targets is ***not*** free on R6x0

- Cost is proportional to number of pixels to clear
- The less pixels to clear the better!

Here the rule about minimum work applies:

- Only clear render targets that need to be cleared!
- Exception for MSAA RTs that need clearing every frame
- Could even use partial Clears using draw calls

RT clears are *not* required for optimal multi-GPU usage



Shader Compiler – Parallel Code

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R6x0 unified shader operates on 5 scalars per instruction

- x,y,z,w scalar units for generic MAD-style operations
- t unit for MAD and special operations (“transcendental”)

Write parallel shader code for best performance

- Enable optimal instruction throughput
- Avoid scalar dependencies

Execute scalar instructions first when mixed with vector ops

- Use parentheses can help

```
float  a;
float  b;
float4 V;

V =  V * (a * b);
```

Shader Compiler – Transcendental Unit

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Operations handled by t unit (on top of generic MAD ones)

- Integer multiplication and division
- Bit shifts
- Type conversion (float to int, int to float)
- Division, reciprocal, square root, reciprocal square root
- log, exp, pow
- sin, cos

Too many of those can cause a bottleneck in your code

In particular watch out for type conversions

- Remember to declare constants in the same format as the other operands they're used with!

Shader Compiler – ALU:TEX ratio

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ALU:TEX ratio on R600/RV670 series is **4:1**

- This is the basic ratio for <=64 bits formats with no filtering
- This ratio is for *hardware* instructions, not D3D ASM ones!
- Feed your shaders into GPUShaderAnalyzer for analysis!

The following require more samples thus affect the ideal ratio

- Advanced filtering (trilinear, anisotropic)
- 128 bit texture formats and 64-bit *integer* format
- Volume textures
- Special texture instructions (e.g. SampleGrad)

Example: sampling three 16161616f textures with trilinear requires up to 24 ALU instructions for a balanced shader

- 3 (textures) x 2 (trilinear) x 4 (ALU ratio) = 24

Shader Compiler – Indexing

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Indexed temporaries will reduce performance when stored in external video memory

- Avoid declaring arrays of temporaries
- The performance impact of temp indexing can be dramatic!

Indexed constants may also be subject to direct memory access

- Especially when indexing larger arrays

You can detect such cases with GPUShaderAnalyzer

- Watch out for the following instructions:

  MEM_SCRATCH_WRITE

  MEM_SCRATCH_READ

  VFETCH

Alpha Test

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Alpha test deprecated in DirectX 10

- Use **`discard()`** or **`clip()`** in HLSL pixel shaders

This requires the creation of two shader versions in DX10!

- One without **`clip()`** for opaque primitives
- One with **`clip()`** for transparent primitives

Don't be tempted to use a single **`clip()`**-enabled shader

- This will impact GPU performance w.r.t. Z culling
- A single shader with a static/dynamic branch will still not be as good as having two versions

Side-effect: contribution towards "shaders explosion"

Put **`clip()`** / **`discard()`** as early as possible in shader

- Compiler may be able to skip remaining instructions

Accessing Depth and Stencil

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DX10 enables the depth buffer to be read back as a texture

Enables features without requiring a separate depth render

- Atmosphere pass, soft particles, DOF, forward shadow mapping, screen-space ambient occlusion, etc.

This is proving very popular to most game engines

- DX10.1: no problem, just re-use the depth buffer in all cases
- DX10: requires a separate depth render path for MSAA
  - Store depth in alpha of main FP16 RT
  - Render depth into texture in a depth pre-pass
  - Use a secondary render target in main color pass

Shadow Maps

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Avoid using **DXGI_FORMAT_D24_UNORM_S8_UINT** for depth shadow maps

- Reading back a 24-bit format is a slow path on R6x0
- No need for stencil for shadow maps anyway

Recommended depth shadow map formats:

DXGI_FORMAT_D16_UNORM

- Fastest shadow map format
- Precision is enough in most situations
  - Just need to set your projection matrix optimally

DXGI_FORMAT_D32_FLOAT

- High-precision but slower than the 16-bit format

Multisampling Anti-Aliasing

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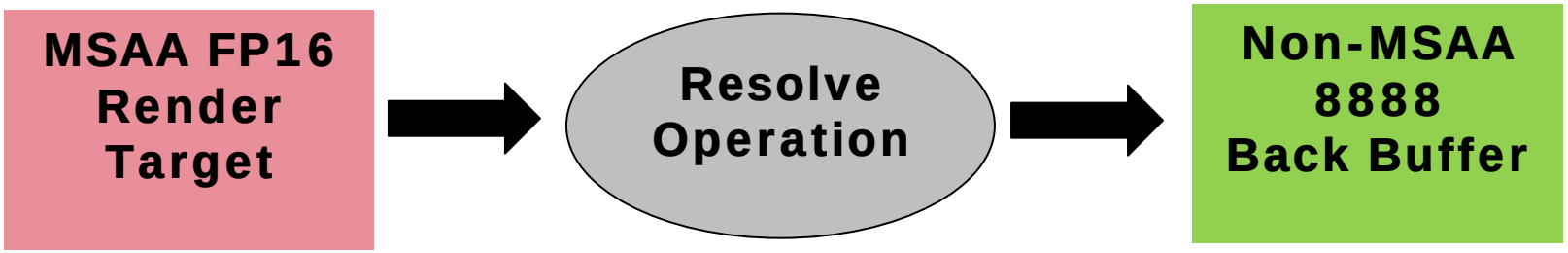
Remember to NOT create your back buffer as multisampled!

- In most cases all multisampled rendering occurs on RT
  - Typically FP16 render target for HDR rendering
- Back buffer only receives resolved contents of RT



MSAA resolve operations are not free (on any hardware)

- This means **`ResolveSubresource()`** costs performance
- It is *essential* to limit the number of MSAA resolves
- Requires good design of effects and post-process chain

Reducing the number of MSAA Resolves 1

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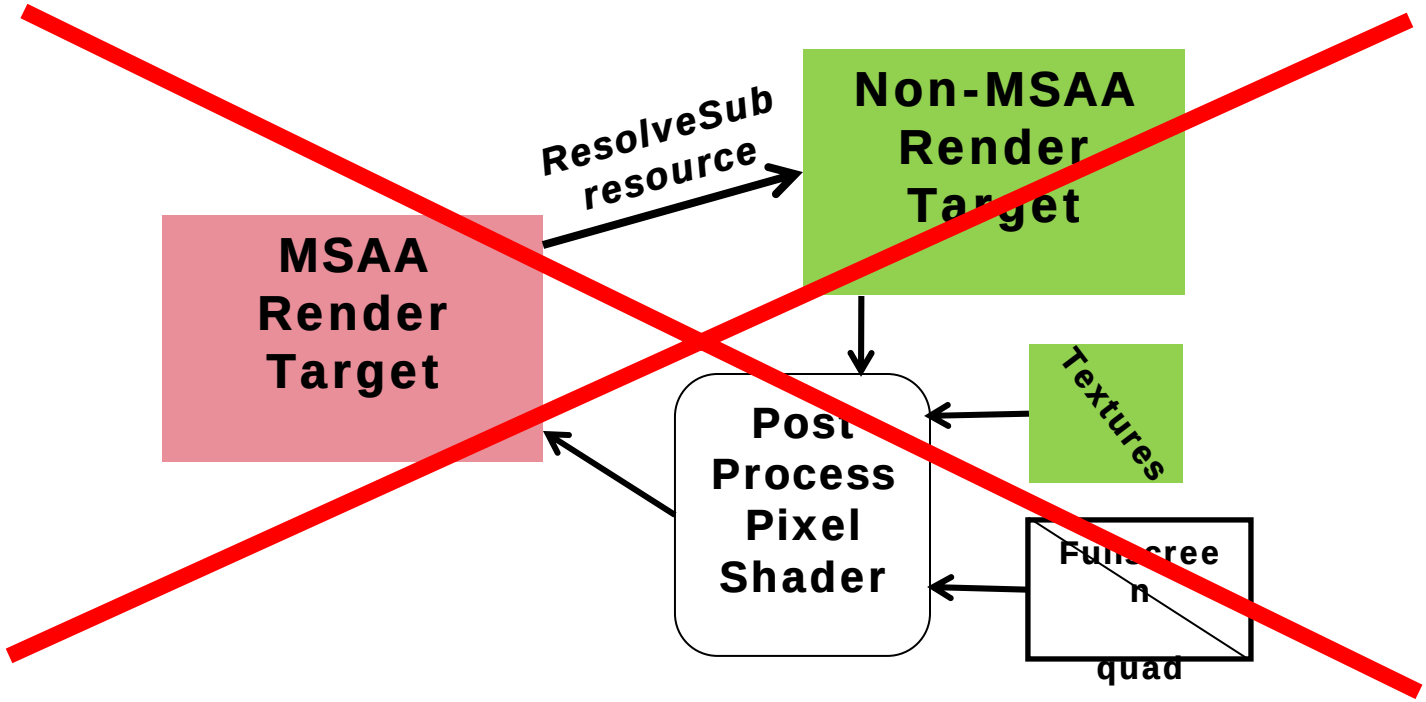
Avoid post-processing image ops on the MSAA buffer!



Especially bad with multiple post-process operations
- Requires multiple resolves
- MSAA rendering for no gain (no edges to antialias!)

Reducing the number of MSAA Resolves 2

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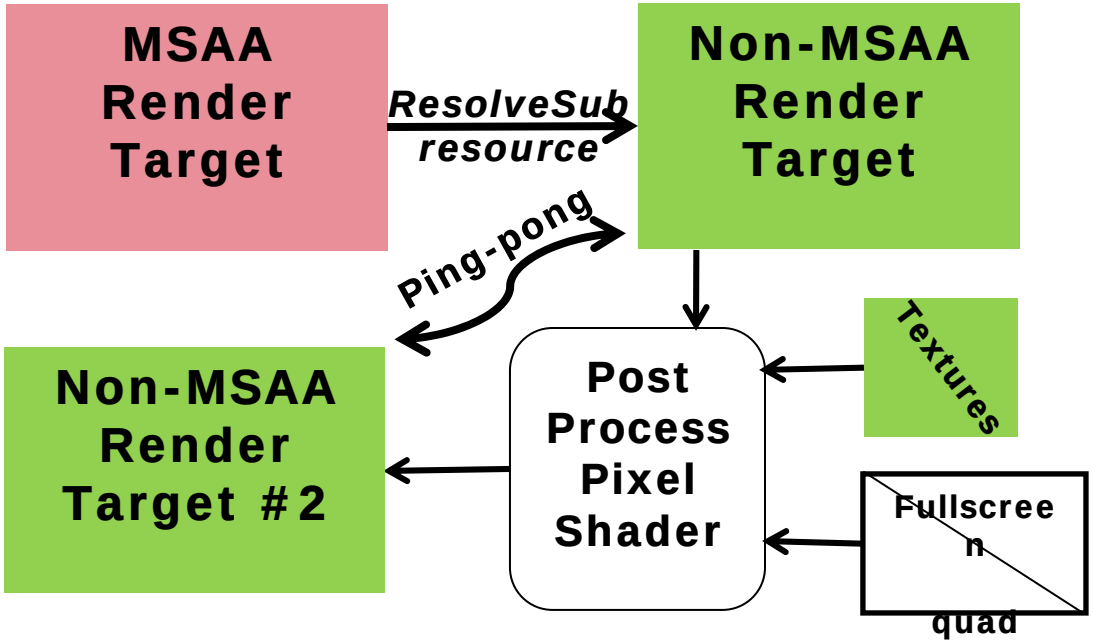
Post-processing image ops should be done on resolved buffer



Resolve MSAA render target once, ***then*** apply post-processing

Ping-pong the two non-MSAA RTs for multiple effects

Reducing the number of MSAA resolves 3

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`Load()` gives individual access to MSAA samples in pixel shader

Allows custom pixel shader-based resolves

- HDR-correct resolves
- Deferred Shading resolves
- Shadow map resolves (DX10.1)

This also enables “cheap” resolves to be carried out

- Can be needed for some post-process effects
- Load() and process a single sample
- Single-sample resolves faster than fixed-function

In the end the scene needs only a ***single*** “real” MSAA resolve

- Subsequent resolves need only be single sample
- ...or better yet, not required

Post-Tone Mapping HDR MSAA Resolve

Standard MSAA resolve occurs before tone-mapping

HDR MSAA resolve should be done ***after*** tone-mapping!

$$ToneMap\left(\frac{\sum_{n=1}^{\#samples} Sample(n)}{\#samples}\right) != \frac{\sum_{n=1}^{\#samples} ToneMap\left(Sample(n)\right)}{\#samples}$$

Standard resolve

Custom resolve

A taste of DX10.1

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DX10.1 released with Windows Vista SP1

- Should be a couple of weeks from now

Next Catalyst release adds DX10.1 support to HD3x00 series

DX10.1 features:

- MSAA depth buffer readback as texture
- Cube map arrays
- Per-pixel coverage output mask
- Mandatory HW support (MSAA 4x, FP32 filtering, etc.)
- Per-sample execution in pixel shader
- Separate MRT blend mode
- New 4.1 shader model (Gather4, samplepos, etc.)
- More precision etc.

Conclusion

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Ensure the DX10 API is used optimally

- Geometry Instancing!
- Right balance of resource updates

Limit Geometry Shader output size to a minimum

Only Clear() when and where necessary

Watch out for unexpected shader compiler output!

- Use GPUShaderAnalyzer

Using a minimum number of MSAA resolves is *essential*

Create a DX10.1 device if supported and use what you need

Questions?

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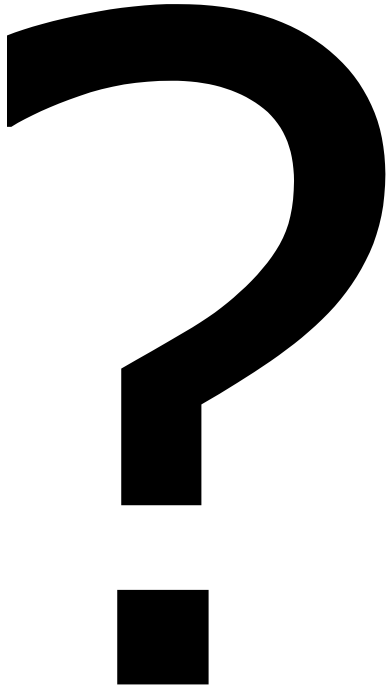

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